EFFECT OF SPORTS TRAINING ON VISUAL PROCESSING IN PERI-HAND SPACE

By

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ABSTRACT

The area immediately surrounding the hand has been shown to give rise to alterations in visual perception. This area is referred to as peri-hand space. When viewing objects in this area, studies have shown that people are slower to look away from objects and faster to detect new objects compared to objects that are not in peri-hand space. The aim of this study is to examine the effects of sports training on altered visual perception in peri-hand space. Practice with motor skills enables the brain to become more plastic and strengthens the brain areas that are repeatedly used. Thus, we hypothesized that athletes would have greater visual processing alterations (hereafter referred to as peri-hand effects or PHE's) when viewing objects in peri-hand space compared to non-athletes because athletes spend far greater time training the visual and motor areas of their brains to be able to use their hands in order to achieve an athletic goal. We tested this by having a group of athletes and a group of non-athletes perform a visual search task where they had to identify a target image amongst an array of distractor images while wearing an eyetracker. We did not find any significant peri-hand space effects and thus, also did not find any main effects of athletic experience on our measures of peri-hand space. We did find that participants were faster to find and react to graspable objects compared to ungraspable objects. The results are discussed in relation to the idea that the lack of PHE's in our results was due to the images in our task being too complex to elicit any PHE's.

Thesis Supervisor: Professor Jenni Karl, Ph.D.

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DEDICATION

I would like to dedicate this project to my wife, who listened to me ramble about peri-hand space for almost a year, and who helped with extra responsibilities as I was writing the days away.

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INTRODUCTION

The area immediately surrounding your hand can give rise to alterations in visual processing, known as peri-hand space effects (PHEs). There is a strong body of literature that suggests that these PHE's are enabled by a subcortical projection to the dorsal vision-for-action stream. The major evidence for this comes from case studies of brain-injured patients with some form of visual loss due to damage in the geniculostriate pathway where it was shown that placing the hands near a visual stimulus was able to ameliorate the effects of the visual loss. Schendel and Robertson (2004), examined a patient who suffered a stroke leaving him unable to see in his left visual field. They tested him on a target detection task with his left arm placed either in close range of the stimuli or far away from the stimuli. What they found was that target detection was significantly improved in his damaged left visual field when he placed his arm near the targets. In order to prove that the visual improvement was not related to a proprioceptive cue, they also projected targets on the patient's left visual field that were at the same eccentricity but out of reach of the patient's left arm. In this condition, the patient's target detection was significantly worse; however, when they gave the patient a tennis racket, his target detection once again improved (Schendel & Robertson, 2004). These results led them to conclude that placing the arm close to the targets in the patient's damaged left visual field led to improved target detection, but not as a result of a proprioceptive cue.

In addition to this study, di Pellegrino and Frassinetti (2000) also ran a case study on a patient with visual loss to see if peri-hand space had any effect on the patient's impaired visual processing. This patient however, suffered from visual extinction due to a stroke. Visual extinction is a disorder where patients will be able to see a stimulus presented on either side of their body; however, when presented with a stimulus on both sides of their body simultaneously, they will not be able to see the stimulus on their contralesional side. What they found was that their patient's extinction was ameliorated when stimuli were presented close to their patient's hand. This suggests that presenting visual stimuli within peri-hand space can diminish the effects of visual extinction in brain injured patients. However, this effect was only present when the hands were visible. Di Pellegrino and Frassinetti ran the same test but covered up the hands of the patient, and the improvement in the damaged visual field disappeared, once again suggesting that peri-hand space effects are not mediated by proprioception, and that sight of the hands is important (di Pellegrino G & Frassinetti, 2000).

Taken together, these findings support the idea that there is a physiological difference between visual processing of stimuli in peri-hand space and visual processing of more distal stimuli. If there was no physiological difference between the two forms of processing, then we would not expect these two patients to experience any changes in their visual perception as a result of their hand position. However, since our patients are displaying improvements in visual perception in peri-hand space, there must be some way that visual information originating near their hands reaches their consciousness awareness. Furthermore, since these patients' primary visual cortices are damaged, this visual information must be taking an alternate route to conscious awareness.

Subsquent research in healthy adults reveals that there are a variety of PHE's that exhibit different effects on visual processing. One of these PHE's is that you may unconsciously conduct a more thorough analysis of things close to the hand. This was demonstrated in a paper by Abrams, Davoli, Du, Knapp, & Paull (2008). They found that participants were unconsciously slower to look away from objects that were in peri-hand space compared to objects that were not. They theorized that this was because objects that are near the hand are more likely to be the subject of manual interactions than objects that are not, and so the brain conducts a more in-depth analysis of those objects to enable accurate manual interactions with it. For example, a marker that is near the hand has a higher probability of being grasped and used than an eraser located across the room. So, theoretically, the marker is subject to enhanced visual processing. Abrams et al. (2008) speculated that paying more attention to objects close to the hand may result in more accurate manual movements. Thomas and Sunny (2017) also found that participants in their study were slow to look away from objects that are in peri-hand space. They agreed with Abrams et al. (2008) that this seems to be because the brain conducts a more in-depth analysis of objects located in peri-hand space. Thus, slower disengagement from objects near the hands, which is proposed to result from a deeper visual analysis, is a consistent occurrence in the literature.

There is also evidence that when objects appear close to the hand, the brain is faster to detect those objects compared to objects that appear farther away from the hand. For example, Reed et al., (2006) conducted a study where participants had to react to a target appearing in one of two predetermined squares. They found that when participants placed their hand near the square, the participants were faster to react to the target appearing in that square. They concluded that the presence of our hands elicits more visual attention in the areas surrounding them compared to away from them. In contrast, Gozli et al. (2012) reasoned that the faster reaction times close to the hand are due to the activation of different visual processing streams. According to their theory, placing the hands near a stimulus biases visual processing towards the magnocellular (M) pathway. This visual pathway contains axons that are larger and can therefore conduct information faster than the other major pathway, the parvocellular (P) pathway (Maunsell et al., 1999). Gozli et al (2012) claimed that the area surrounding the hands biases visual processing towards the M pathway. Thus, the faster reaction times observed by Reed et al. (2006) may have been due to the faster processing of the M cells compared to P cells. The findings of Thomas & Sunny (2017) agree with both Abrams et al. (2008) and Gozli et al. (2012). They found that participants were faster to react to targets that were located near the hand, however they reasoned that this was because of the bias towards the M pathway, not because of attentional prioritization. In sum, the presence of the hand may elicit a greater bias towards M pathway processing, and more in-depth analysis of objects, resulting in slower visual search, but faster reaction times.

The ability to correctly identify certain objects, such as food, is evolutionarily advantageous, therefore an additional PHE that is relevant to this study is accuracy. Adam, Bovend'Eerdt, van Dooren, Fischer, & Pratt (2012), ran a study to examine what role peri-hand space might play in correct target identification. In this study, participants had to correctly identify letters that were displayed on a screen. The participants' hands were placed on movable pads that were placed at three different distances from the letters: close, intermediate, and far. They found that as the participants' hands got closer, the participants became more accurate in identifying the letters. In order to establish whether the three letters paradigm was too easy, Adam et al. (2012) repeated this experiment with a more difficult task. The participants hands were placed in the same pads at the same distances, but this time they had to sort between six different letters. Three of the letters were red and three of them were white. The participants once again had to identify the white letters only, only now they would have to sort through the red letters as well. Once again, Adam et al. (2012) found that the participants were able to correctly identify more letters when their hands were close to the letters compared to far away. These results lend support to the idea that target identification is more accurate when the target is close to the hands.

It has been demonstrated that the aforementioned PHEs can be modulated by certain factors. Peri-hand space effects are not always easy to replicate, and some recent papers have discussed this difficulty in replicating PHE’s (Dosso & Kingstone, 2018). Thomas and Sunny (2019) came to a similar conclusion to Dosso and Kingstone about the fragility of PHE’s. In Thomas and Sunny’s (2019) experiment, they had participants identify either an “E” or “F” among distractor letters either near or far from their hand, testing to see if participants were faster to respond when the letter arrays were close to the hand. They conducted two experiments where they manipulated the placement of the arrays on a computer screen to see if hand placement had any effect on reaction times. In both of their manipulations they were unable to find any evidence of hand placement having an effect on reaction times. They stated that perhaps their, “far” conditions were not far enough away from the hands to show a difference, or perhaps distinguishing between letters actually biases the participants away from using the parts of their brain that enable PHE’s. Their overall conclusion was that PHE’s seem to be very sensitive to the task being performed, and much care needs to be taken when designing a paradigm intended to find PHE’s (Thomas & Sunny, 2019)

One factor that might be particularly relevant for finding PHEs are the action-relevant affordances provided by the object itself. Affordances are actions that are made possible by the shape of the object. For example, a typical coffee mug affords grasping by the handle, or a shopping bag affords carrying through the straps. Chan et al. (2013) demonstrated that these affordances are able to influence object perception. They utilized a task where participants were shown an object and were required to say whether the object was bigger than a shoebox or not using two different keys on a keyboard. They found that participants were fastest at identifying the object when they were presented with graspable objects near the hand (Chan et al., 2013). They concluded that whether an object is graspable or not may affect the speed of visual processing of that object when it is located within peri-hand space.

Neural Underpinnings of Peri-Hand Space

Neurophysiological studies suggest that when a person views an object near their hand, PHE's are enabled by a subcortical pathway that bypasses the primary visual cortices and instead carries this information from the retina to the pulvinar, and then to the middle temporal area (Mundinano et al., 2018). The middle temporal area then feeds directly into the dorsal stream of vision, which contains networks responsible for generating reaching, grasping, and visual processing for objects near the hand (Born & Bradley, 2005; Goodale & Milner, 1992). This subcortical transmission to the middle temporal area and dorsal stream is faster than other forms of visual processing which generally have to go to the occipital lobe first. This fast transmission is what is thought to enable peri-hand space effects. (Brown et al., 2008; Schendel & Robertson, 2004; di Pellegrino G & Frassinetti, 2000). The visual information that the person has at this point is thought to be enough to allow for a crude reaching movement. As the person's hand gets closer to the object that they are looking at, the reach and grasp areas of the dorsal stream send information about the shape of the object the person is reaching for, as well as the speed and shape of their hand back to the occipital lobe. The occipital lobe can then fine tune the visual information that is sent from the primary and secondary visual areas to the middle temporal area and eventually the dorsal stream, which may provide more detailed visual information to the reach and grasp networks in the parietofrontal lobe (Perry & Fallah, 2017; Perry et al., 2016). These networks include the anterior and posterior intraparietal sulcus (IPS), the lateral occipital cortex (LOC), the supramarginal gyrus (SMG), and the premotor cortex (PMC) (Maimon-Mor et al., 2017). The refined visual information sent to these networks is then thought to allow for more refined hand preshaping and orienting towards the object that is being reached for.

There are a number of candidate subcortical visual pathways that could be enabling PHEs (Brown et al., 2008; di Pellegrino G & Frassinetti, 2000; Makin et al., 2012), but one particular pathway stands out. Mundinano et al. (2018) reported that the retino-pulvinar-MT pathway (RPMT) pathway is a transient. They report that this pathway relays visual information to the middle temporal area (MT) and the dorsal stream during early development in order to facilitate certain behaviors that are important for survival shortly after birth, such as grasping onto food items, branches, or clinging to parents. Interestingly, Mundinano et al. (2018) also lesioned this pathway in infant marmoset monkeys and found that the lesioned monkeys displayed abnormal development of reach and grasp behaviors. This implies that this pathway could have some importance in the proper development of visually guided actions. However, they suggest that the RPMT pathway soon fades as cortical visual areas that project to the dorsal stream strengthen with age. Thus, we hypothesized that athletic experience might utilize the visual information that is transmitted quickly through the RPMT pathway, and through repetitive use, prevent the RPMT pathway from fading away with age.

The altered visual processing that arises from PHE's is processed faster but at the cost of accuracy. There is a speed/accuracy trade-off when it comes to visual processing. The dorsal stream is specialized for rapid processing of objects that are in motion or are to be acted upon. The ventral stream specializes in object discrimination and processing very detailed information, but at relatively slower speeds (Goodale & Milner, 1992). The speed/accuracy trade-off results from the characteristics of the two streams. The dorsal stream provides quick information with less detail, the ventral stream provides much detail, but relatively slower. Since the pathway that enables PHE’s lies in the dorsal stream of vision, it is likely that this visual information is processed faster, but with less detail then ventral stream processing.

Effect of Athletic Experience on Neural Physiology

Athletic experience has been shown to affect overall brain plasticity. For example, Gao et al. (2019) recruited tennis and ping pong players and performed MRI scans on them, as well as control participants, at the start of their study. The athletes were then given a year of training in their sport and were scanned again. They found that the athletes showed increased grey matter volume (GMV) compared to non-athletes (Gao et al., 2019). Importantly, they found this increased GMV occurred in the areas of the brain involved in visuomotor coordination, such as the right parietal operculum, posterior cingulate cortex, right insula, and the superior parietal lobule extending to the intraparietal sulcus. (Gao et al., 2019)They also found that these visuomotor areas showed enhanced functional connectivity with other brain areas that were related to internal and external attention (Gao et al., 2019). In another example, Pi et al. (2019) performed diffusion-tensor imaging on the brains of national level basketball players compared to the brains of students who had no formal training in sports. They found that athletes had more efficiently organized visuomotor brain networks. Much of the increased neural plasticity that they found took place in the proposed peri-hand brain network (Brozzoli et al., 2014).

In addition to overall plasticity and increased GMV, athletic experience can also affect the speed of nerve conduction in the brain. Zwierko, Osinski, Lubinski, Czepita, & Florkiewicz (2010), tested the reaction times of division 1 male volleyball players versus untrained control participants. They found that the volleyball players had shorter reaction times to stimuli compared to their non-athletes. Importantly, they were able to show, by measuring visual evoked potentials, that the difference in reaction time was due to faster signal transmission in the central nervous systems of athletes (Zwierko et al., 2010). They concluded that the faster speed of transmission in athletes was a result of playing a sport that demanded a lot of sensory and motor nervous system activation. By looking at these examples, it is clear that athletic experience not only strengthens the body, but the brain as well.

Athletic experience has also been shown to strengthen certain aspects of visual processing in peri-hand space. Biggio et al. (2017) looked at whether using a personalized tennis racket or a generic racket had an effect on the extension of peri-personal space in participants of varying levels of tennis experience. They found that when experienced tennis players used their personal racket, they were able to verbally respond faster to a far stimulus compared to a close stimulus. When experts used a generic racket, there was a larger difference between near and far stimuli reaction times, and novices had an even larger difference in reaction time between near and far stimuli. These results give another great example of athletic experience, in this case with a tool (tennis racquet) modifying the boundaries of peri-personal space by expanding them to incorporate the end of the tool. Biggio et al's. (2017) result suggests that motor experience is able to strengthen and expand the neural processes taking place in the peri-hand brain network.

The aim of the current study was to evaluate whether playing a sport without the use of a tool could enhance, not the boundaries, but visual processing within peri-hand space. We hypothesized that if visuomotor practice leads to strengthening of connections and increases in GMV within the peri-hand brain network, then peri-hand space effects related to the visual processing of objects near the hand would be more enhaned in athletes compared to non-athletes. Abrams et al. (2008) and Thomas and Sunny (2017) concluded that participants have longer overall search times within peri-hand space because the brain conducts a more in-depth analysis of objects closer to the hand. In line with these results, we hypothesized that participants would have longer overall search times within peri-hand space compared to without. Based on Reed et al. (2006) and Gozli et al. (2012), who found that participants were faster to react to stimuli placed close to their hands due to a bias towards M-pathway processing, we hypothesized that participants would be faster to recognize when they were looking at the target image. Finally, Adam et al. (2012) found that participants were more accurate in identifying letters on a screen when their hands were close compared to far away; and so, we hypothesized that participants would be more accurate at identifying the target image in peri-hand space compared to without. In addition, we predicted that all of these effects would be enhanced in athletes compared to non-athletes. We tested our hypotheses using a visual search task, where participants completed the task within and beyond peri-hand space. Participants wore an eye tracking camera, which enabled us to measure the overall time it took them to conduct each trial, and the amount of time it took for participants to recognize that they were looking at the correct target. Both athletes and non-athletes completed the task and their scores were averaged and compared against each other.

Methods

Participants

Control participants were recruited from Thompson Rivers University psychology classes (n = 25). These participants were of any age or gender. Athlete participants were recruited from the Kamloops Broncos (n = 14). The criteria for being an athlete was as follows: the athlete must have been playing a sport that involved some form of catching for at least five consecutive years, and they had to have been either playing their sport at the time of the study or their season had to have finished within the year of the study. These participants ranged in age from 18 to 22 years. Athlete participants were recruited through word of mouth and were compensated with a fivedollar Tim Hortons gift card. Control participants were recruited through SONA, which is a research website that allows students to sign up for available timeslots. Students were notified by their professors about the opportunity to earn credit toward their final grade. Student participants were compensated with 2% towards their final grade in their psychology class. All participants were given a letter of information, informed consent from, and a photo release form as required by the Thompson Rivers University human ethics committee. All participants were notified of their right to withdraw at any time without consequence. Participants with any known sensory, motor, or neurobiological disorder were excluded. All research procedures received Thompson Rivers University Research Ethics Board approval.

Design

This study was a 2 Athletic Experience (athlete vs. non-athlete) x 2 Hand Position (hand-close vs. hands-far) x 2 Graspability (graspable vs. ungraspable) mixed design. The order of hand position and graspability was randomized and counterbalanced across all participants. Participants were assigned to the athlete or non-athlete group based on their athletic experience.

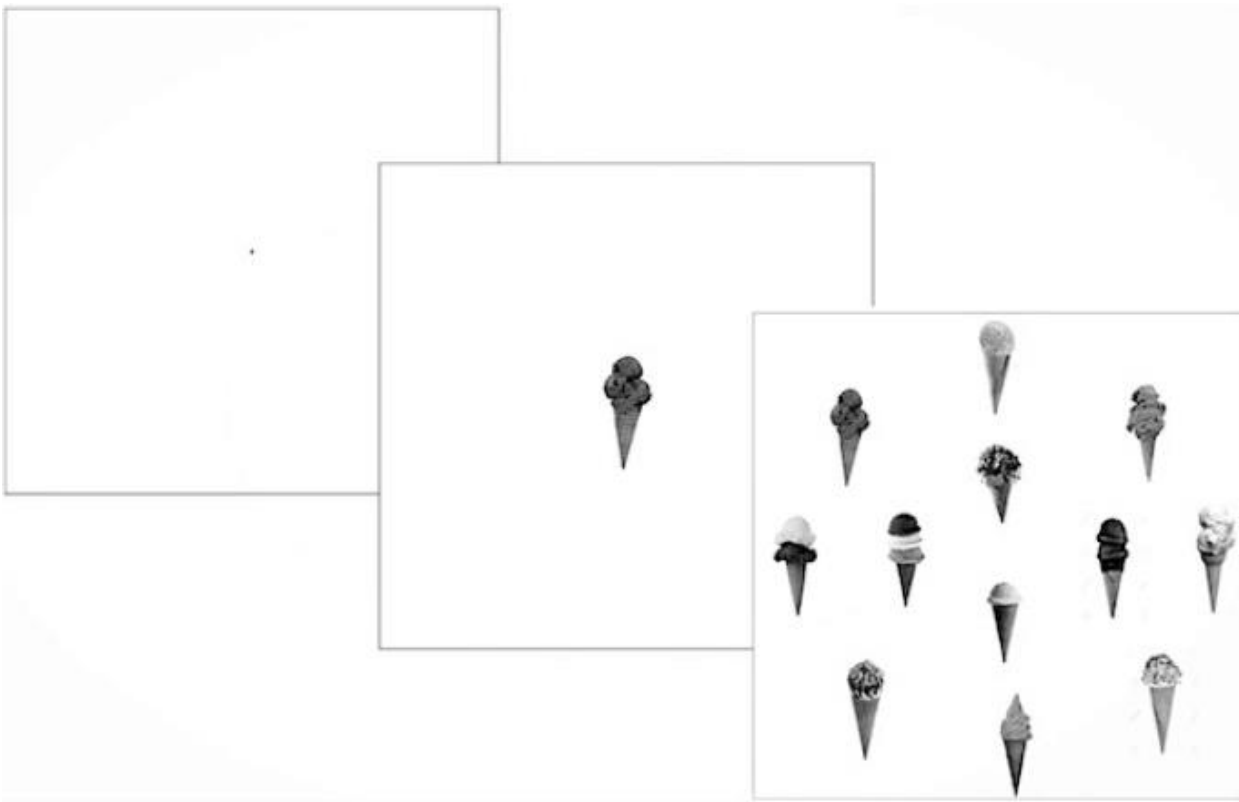
Procedure

Once each participant arrived, they were given a letter of information, an informed consent form, and a photo release form. They were then asked to provide a brief history of all of the organized sports they had played in their lifetime (if any), and for what age ranges they played those sports. Once these steps were completed, they were seated in front of a computer and fitted with the eye-tracker. The eye-tracker had two cameras mounted on it, one to record the eye and one facing forward to record the computer screen. These cameras record at an average of 85 frames per second. The eye-tracker worked by shining an infrared light onto the participant's cornea to produce a corneal reflection and then triangulating the reflection of the light relative to the pupil of the eye and the scene that the participant was looking at. This technology allowed us to determine what part of the stimulus presentation screen the participant was looking at during the experiment. Once a participant completed their session, the video from that session was ran through a program called Yarbus. Yarbus is able to calibrate the information from the infrared light and render a blue dot on the video of the scene that shows where the participant's gaze was directed. The monitor that the participants sat in front of was adjusted so that the target fixation cross on the monitor was directly eye level with the participant. The keyboard was raised to be 10cm away from the bottom of the monitor. For the hands-far condition, the participant placed their right hand in their lap, and their left index finger on the spacebar. For the hands-close condition, the participant placed their right hand on the side of the monitor in an open position and their left index finger on the space bar. The participants completed 10 practice trials, five in the hands-close position and five in the hands-far. The participants were all instructed to complete the task as quickly and accurately as possible. After they successfully completed these trials, they were ready to begin the task.

To start the task, the participants were instructed to start with either their right hand in their lap, or on the side of the screen. The order of these conditions was counterbalanced across participants. The participants then used their left index finger to hold down the spacebar. As soon as the space bar was pressed down, a crosshair appeared in the middle of the screen. After 1 s the crosshair was replaced with a target image. After a further 2 s, the target image was replaced with a visual array (see Figure 1).

Figure 1

Ice Cream Array



Note. Order of the task and example of the ice cream cone array. Adapted from "Peri-Hand Space: A Potential Helping Hand for Faster Target Recognition in Children" by N. Klassen.

There were eight different arrays, each consisting of 12 different images from a particular category. The array included 11 distractor images and the target image. The arrays were divided equally into graspable or non-graspable images. The graspable arrays contained various images of cell phones, toys, wrenches, and ice cream cones respectively. The non-graspable arrays consisted of people, houses, boats and horses respectively. The participant's task was to find the original target image and touch it on the screen with their left index finger. Once the participant had touched the screen, the array disappeared, and the trial was complete. The next trial did not begin until the participant held the spacebar again. Each experiment consisted of 40 trials. After the 40th trial, a message appeared on the screen saying, “Thank you for completing this testing session.” After this, the participant’s information was re-entered into the program, and they completed another 40 trials under the opposite hand position condition.

The computer program recorded 5 different pieces of information. It recorded the amount of time from when the array appeared to when the participant released the space bar, the amount of time between releasing the spacebar and the participant touching the screen, whether the participant selected the correct image on the screen, the precision of the participant’s touch on the image, and the total amount of time from when the array appeared to when the participant touched the screen. The order in which the arrays appeared was randomized and counterbalanced, and no array could appear more than 5 times in 40 trials. The location of the target image was also randomized, and no target location could be used more than 5 times within 40 trials. The target image would only appear in the 8 locations around the outside of the array, never in the 4 locations in the middle. This was because the inner starting locations were too close to the original crosshair to obtain accurate measurements. The target image was also randomized so that any image could only serve as the target image once in all 40 trials.

We also collected survey data on the difficulty of our arrays. Using surveymonkey.com, we created a survey where participants viewed a slideshow that simulated the task. The slideshow would automatically present the crosshair, and then target image, and then the array for each set of objects. Participants were then given a picture of each array and asked to rate on a Likert scale how difficult or easy it was to find the target amongst the array (1 – very easy, 2 – easy, 3 – neither easy nor difficult, 4 – difficult, 5 – very difficult). Participants for this survey were also recruited through SONA and were not the same participants that participated in the visual search task. These participants were offered 0.5% towards the final grade of their psychology courses for their participation.

Data Analysis

This study used a mixed experimental design and involved three independent variables, one between-subjects and two within-subjects variables. The first, athletic experience, served as the between-subjects variable. The two levels of athletic experience were athlete and non-athlete. The second independent variable was hand position, and the two levels here were hands-far and hands-close. In the hands-far condition the participant placed their right hand on their lap, putting the visual search task outside of peri-hand space. In the hands-close condition, participants placed their right hand on the side of the stimulus presentation screen, so that the task was within peri-hand space. The third independent variable was whether the objects in the visual search task were graspable or not. The three dependent variables that were examined included accuracy (A), visual search time (VST), and target fixation duration (TFD). Accuracy is calculated by dividing the number of trials in which the participant correctly identified the target in the array by the overall number of trials (40) in each hand position condition. Therefore, an accuracy score of 1 means that the participant correctly identified all 40 of the target images amongst their arrays: 40/40 = 1. VST represents the amount of time the participant spends looking for the target. To obtain this measure, we subtract the frame number of when the array first appeared (array) from the frame number of when the participant first fixates on the target image (fixate), and again divide by the frame rate: (fixate – array)/rate = VS. TFD represents the amount of time that the participant fixated on the target image before releasing the spacebar in order to reach out and touch it. It is a measure of the amount of time required for the participant to recognize that the object they are looking at, is indeed the target image. To calculate TFD, we subtract the amount of time that the participant took to touch the correct image (touch), from the amount of time that it took them to release the spacebar in seconds (spacebar release). We also subtract the frame of when they first fixate on the target (fixate) from the frame of when they touch the target (touch). We then subtract the first value (touch – spacebar release) from the second value (touch – fixate) to give us TFD: ((touch – fixate) – (touch – spacebar release))/rate = TFD.

Results

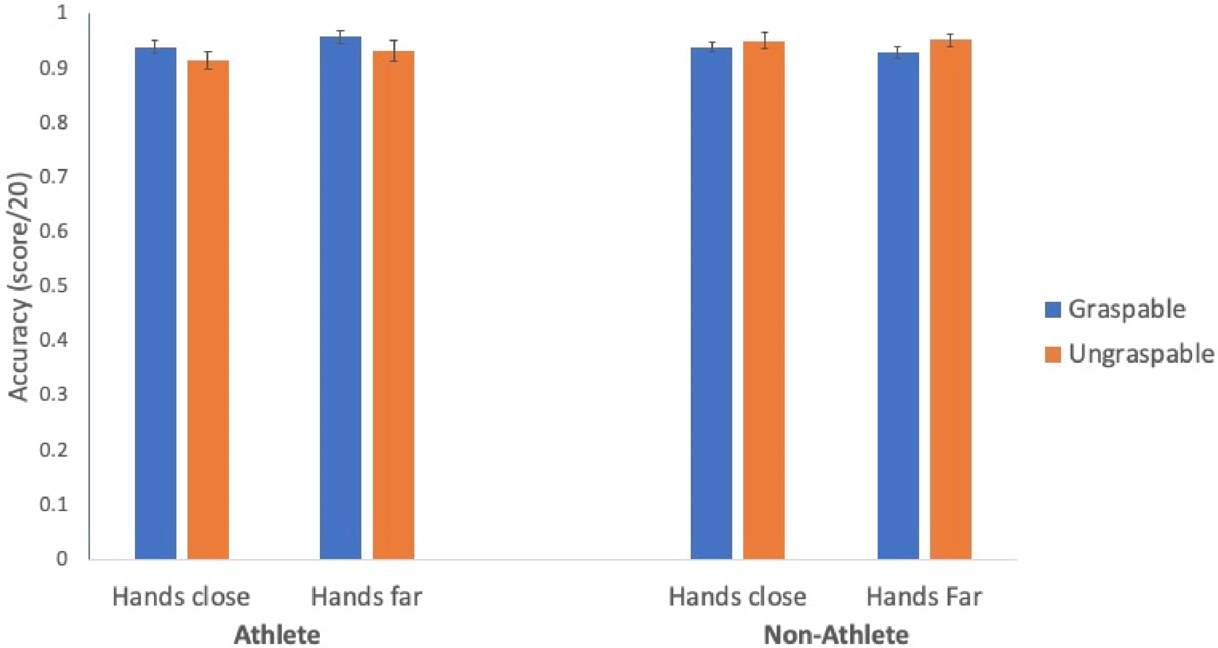
This study utilized a mixed methods ANOVA to examine the effects of athletic experience, hand position, and graspability on three measures of visual processing: accuracy, visual search time, and target fixation duration. We ran the ANOVA and looked for a main effect of athletic experience, a main effect of hand position, and a main effect of graspability. We also examined whether there were interaction effects for athletic experience by hand position, hand position by graspability, and athletic experience by graspability. Lastly, we looked for a three-way interaction between athletic experience, hand position, and graspability. The results showed no significant main effects of any kind on accuracy; however, there was a significant interaction effect of athletic experience by graspability on accuracy. For VST there was a significant main effect of graspability, but again no other significant effects. Finally, for TFD, the results showed a significant main effect of graspability and no other significant effects.

Accuracy

Accuracy was defined as the proportion of trials that the target was correctly identified. The statistical analysis revealed no main effects of athletic experience, $F(1, 37) = .49$, $p = .49$, $\eta_p^2 = .01$; hand position, $F(1, 37) = .48$, $p = .49$, $\eta_p^2 = .01$; or graspability, $F(1, 37) = .2$, $p = .66$, $\eta_p^2 = .01$ on accuracy (see Figure 2). There was only one significant interaction effect of athletic experience by graspability $F(1, 37) = 4.43$, $p = .04$, $\eta_p^2 = .11$, such that regardless of hand position, athletes were more accurate at identifying graspable objects compared to non-graspable objects while the reverse was true for non-athletes. Nonetheless, post hoc paired t-tests revealed no significant differences in accuracy between graspable versus ungraspable objects within the athlete group and within the non-athlete group. The non-significant main effect results indicate that participants were equally accurate at identifying the target object in the array regardless of their previous athletic experience, the proximity of their right hand to the stimuli, and whether the array consisted of graspable or non-graspable objects. However, the significant interaction effect suggests that athletes were able to correctly identify a greater proportion of graspable objects to ungraspable objects compared to non-athletes.

Figure 2

Accuracy



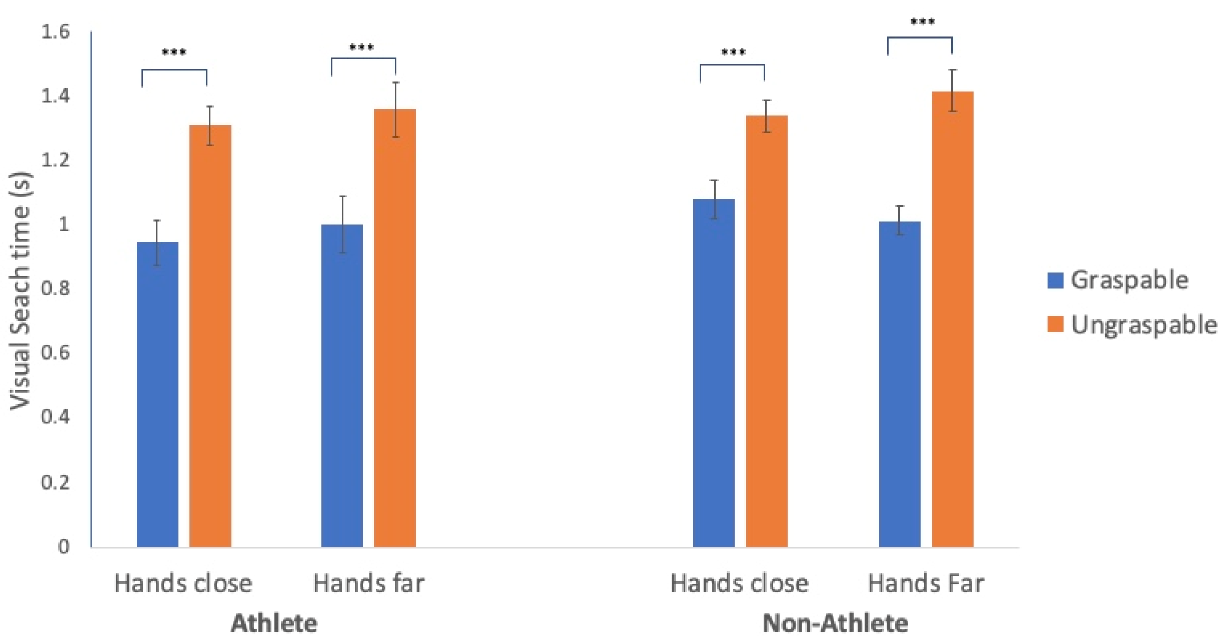
Note. Effect of hand-position, graspability, and athletic experience on accuracy.

Visual Search Time

Visual search time represents the amount of time the participant spent looking for the target image before fixating on it. There was no significant main effect of athletic experience, $F(1, 37) = .655$, $p = .423$, $\eta_p^2 = .017$, or hand position $F(1, 37) = .534$, $p = .47$, $\eta_p^2 = .014$, on visual search time (see Figure 3). There was a significant main effect of graspability on VST, $F(1, 37) = 92.623$, $p < .01$, $\eta_p^2 = .715$, where participants displayed shorter VST's when viewing graspable items ($M = 1.01$, $SE = .037$) compared to when they viewed ungraspable items ($M = 1.355$, $SE = .043$). There were no significant interaction effects for VST. The significant graspability result indicates that participants took less time to find graspable objects compared to non-graspable objects.

Figure 3

Visual Search Time



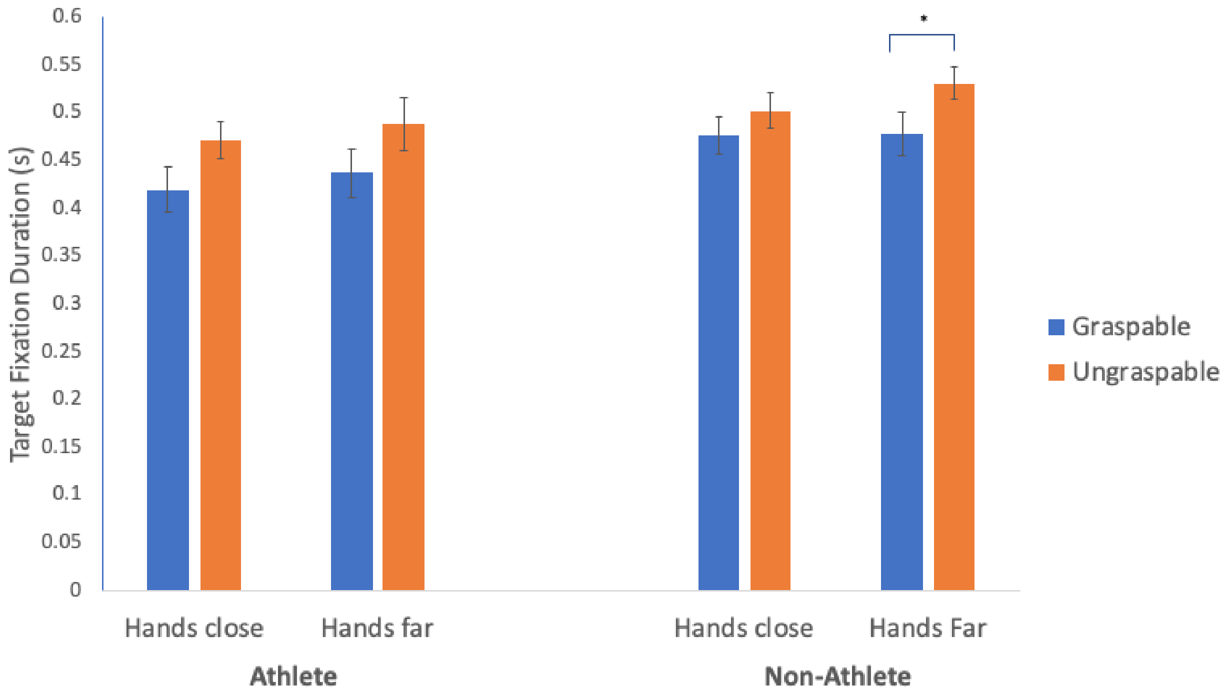
Note. Effect of hand-position, graspability, and athletic experience on visual search time.

Target Fixation Duration

Target fixation duration was defined as the amount of time from when the participant first looked at the target image to when they released the spacebar and serves as a measure of object recognition time. The analysis revealed that there were no significant main effects of athletic experience, $F(1, 37) = 2.811$, $p = .102$, $\eta_p^2 = .071$, or hand position, $F(1, 37) = 1.248$, $p = .271$, $\eta_p^2 = .033$, on TFD (see Figure 4). There was however a significant main effect of graspability, $F(1, 37) = 29.244$, $p < .01$, $\eta_p^2 = .441$, such that participants displayed shorter TFD times when presented with graspable objects ($M = .453$, $SE = .014$), compared to ungraspable objects ($M = .498$, $SE = .013$). This means that after first fixating on the target, participants took less time to lift their fingers off of the space bar for graspable objects compared to ungraspable objects. There were no significant interaction effects. These results show that hand position and athletic experience had no significant effect on how long it took participants to recognize and respond to the target image after they first fixated on it.

Figure 4

Target Fixation Duration



Note. Effect of hand-position, graspability, and athletic experience on target fixation duration.

Array Difficulty

The survey was analyzed using a paired sample Bayesian static test comparing graspable to ungraspable arrays for 183 participants. We also ran a t-test to compare the results of the graspable arrays versus the ungraspable arrays. The results show that there was a significant difference between the graspable and ungraspable arrays $t(182) = 4.37$, $p < .001$, Bayes Factor = .002 such that participants reported being able to find the target easier for graspable arrays (M = 2.38, SD = 0.84) compared ungraspable arrays (M = 2.62, SD = 0.80).

Discussion

The goal of the current study was to investigate whether athletic training was able to enhance visual processing in peri-hand space. If motor training increases neural plasticity in the brain regions involved, then athletes who use the areas of the brain implicated in PHE’s should see an enhancement of those effects compared to non-athletes. We were specifically looking to see whether athletes would be more accurate, take less time to recognize that they were looking at the correct target, and take more or less time to find the target in general compared to non-athletes. We tested these hypotheses using a visual search task where participants had to find a target image amongst 11 distractor images. They each completed this task in two conditions. In the first condition the participants placed their right hand in their lap. This way the array was not in peri-hand space. In the second condition the participants placed their right hand on the side of the screen, putting the array in peri-hand space. This paradigm allowed us to compare various measures of visual processing when the stimuli were in peri-hand space compared to out of it. Our study showed three significant results. We found that athletes had a higher ratio of correctly identified graspable objects compared to ungraspable objects, while the opposite was true for non-athletes. We also found that all participants had significantly shorter VSTs and TFDs when viewing graspable objects compared to ungraspable objects.

A major strength of this study was the fact that it involved some action on behalf of the participant. As Gozli et al. (2012) reasoned in their study, part of the basis for altered processing near the hands is that placing one's hands near a stimulus may bias visual processing towards the M-pathway which is thought to be used for processing action-relevant stimuli. Since the current study involves reaching out and touching the visual stimuli, we should, theoretically, be biasing our participants towards using their M-pathways. Another strength of our study is the use of eye-tracking technology which allows us to find unique measures such as TFD and VST that other studies do not allow for. The eye-tracking technology is able to show us the exact point in time when the array appears, when the participant first looks at the target, and when they finally interact with the target. Using these measures we were able to gather unique insights into the amount of time it was taking our participants to process individual images in the arrays.

Nonetheless, a few limitations of the present study should also be noted. The present study may have encountered a similar limitation to the one that Thomas and Sunny (2019) encountered in their study. Thomas and Sunny reported that they may have been unable to find a hand position effect because distinguishing between the features of different letters may lead to a bias towards p cell and ventral stream processing (Thomas & Sunny, 2019). Our task is relatively similar to that of Thomas and Sunny's, requiring participants to distinguish between the features of images that bear a lot of resemblance. In fact, the present study may be even more difficult to distinguish between images, due to the complex nature of the images relative to Thomas and Sunny's simple letters of the alphabet. If Thomas and Sunny's conclusion about a bias towards ventral stream processing is true, then that could play a large in role in why we were unable to find a hand position effect in our study.

We may have also encountered limitations in regards to the amount of time that participants were given to learn this task and to the sample population of our athletes. Athletes and non-athletes alike had to learn this task in about five minutes and then perform as best as they could. This may have been a limiting factor towards eliciting an effect of athletic experience, as the athletes could have needed to involve their visual cortex in order to teach themselves how to perform this task. According to our theory, PHE's are enabled by a pathway that bypasses the visual cortex, so if the visual cortex is no longer being bypassed then we would not expect to see any difference in processing speeds. A final potential drawback of this study is that the athletes of this study come from an amateur football team. This means that the caliber of athletic ability is somewhat lower than other studies. This may make it more difficult to find the neural adaptations that we are hypothesizing result from athletic training. For example, Pi et al (2019), used athletes from the Chinese national team who had experience competing on the national or international stage. Perhaps a higher caliber of athlete would also display greater neural adaptations.

Additionally, using surveymonkey.com we were able to obtain data on how difficult our target images were to find in their respective arrays. Using this data, we were able to match the ungraspable and graspable arrays according to their perceived difficulty. A paired samples t-test of the results revealed that participants rated the graspable targets as easier to find compared to ungraspable targets. If participants found it easier to distinguish between images in our graspable array regardless of any effects on visual processing, then that could have skewed our results. However, it is also possible that our participants reported having less difficulty with graspable arrays due to the graspability effects reported by Chan (2013), Colman et al. (2017), and Perry et al. (2016). Although, it should be noted that the participants who completed the survey did not complete the real visual search task. Participants who completed the visual search task were also asked (informally) which of the arrays they perceived to be the most difficult, and those participants rated the wrenches as the most difficult, which are a graspable array. One final limitation was the amount of athletes that we were able to recruit for our study. Due to time constraints, we were only able to recruit 14 athletes, and a power analysis conducted by our lab suggested that a sample of 30 would be recommended to reveal a small to moderate effect of hand position. Future research should aim to collect a minimum of 30 participants.

Future research should manipulate the perceived difficulty of the stimuli in the visual search task to determine if there is a statistically significant relationship between perceived target difficulty and visual search time/target fixation duration time. One way that this could be done would be to use the survey and the visual search task data, and run a correlation for each array between perceived difficulty and TFD/VST. If this correlation showed a positive relationship where TFD and VST increased with the perceived difficulty of the array, it would provide evidence that the difficulty of our arrays is a confound in the present study. However, if this correlation were to show no relationship, then we would have some evidence that there were no confounds in the visual search task.

We did not find any significant main effects of athletic experience, hand position, or target graspability on our measure of accuracy. We did however find a significant interaction effect of athletic experience by graspability. According to this result, athletes had a greater ratio of correct target hits to incorrect hits for graspable targets (see Figure 2). Athletes, and especially football players (who made up a majority of the athlete sample), are often required to quickly dissect visual information in order to make the correct athletic move. In football this also requires sorting through misdirection that the other team presents. For an athlete, fast and reliable processing of visual information is crucial. Continued practice of this skill may have contributed to this interaction effect. As for the lack of significant main effects, one reason could be that we were experiencing a ceiling effect. It may have just been too easy to pick the target image most of the time, resulting in us not being able to find any main effects on accuracy. Future research could address this issue by using a task that is difficult enough that participants show more variability in their ability to correctly identify objects, keeping in mind the research demonstrating the fragility of PHE’s (Dosso & Kingstone, 2018; Thomas & Sunny, 2019).

In terms of visual search time, we found a significant effect of graspability on VST (see Figure 3). What was interesting about this result is that it was opposite from what the literature would suggest. According to Thomas and Sunny (2017) and Abrams et al. (2008), VSTs should be greater in peri-hand space because the brain may conduct a more in-depth analysis of the objects surrounding the hand; however, in this study we found that participants had shorter VSTs when looking at graspable objects compared to ungraspable objects. A possible explanation for this relates to the earlier mention that perhaps our stimuli are too complex and bias visual processing towards the p cell pathway and ventral stream that is involved in conscious perception of object identity (Thomas & Sunny, 2019). If all of our stimuli are complex, then perhaps visual processing for images that are close to the hand are just as slow as the visual processing for objects far from the hand. This would eliminate the PHE described by Abrams et al. (2008) of slower visual disengagement from objects near the hand. Then, if you consider the research of Chan (2013), Colman et al. (2017), and Perry et al. (2016) who all agree that graspable objects should be able to prime visual processing back to M-pathway processing (located in the dorsal stream of vision) and therefore speed visual processing up, it would make sense to see shorter VSTs for graspable objects, regardless of hand position. So, it is possible that the images in our study are too complex to see the PHE reported by Abrams et al. (2008); however, the graspable arrays are still able to prime our participants' visual processing back towards M-pathway processing, leading to faster visual processing and shorter VSTs for graspable objects.

We found a significant main effect of graspability on TFD (see Figure 4). This finding is in line with much of the current literature (Abrams et al., 2008; Thomas & Sunny, 2017; Gozli et al., 2012). We found that on average, participants had a shorter TFD when the arrays consisted of graspable objects compared to ungraspable. That is to say, when participants were presented with graspable objects, they spent less time looking at an image before identifying it as the image they were looking for and releasing the spacebar. According to Perry et al. (2016), graspable objects may be preferentially processed in the dorsal visual stream in parallel to the ventral visual stream. So, for the current result, perhaps what we are seeing is that similar to our VST result, the ungraspable images are too complex to elicit PHE's on their own, as they bias visual processing towards the ventral stream. However, the graspable images may prime visual processing back towards the dorsal stream, and faster visual processing (Chan et al., 2013; Colman et al., 2017; Gozli et al., 2012). This would result in participants being able to react to graspable objects faster than ungraspable objects.

We did not find the predicted effect of athletic experience on any of our measures of visual processing, save for the interaction effect of graspability by athletic experience. While it certainly cannot be said that athletic experience has no effect on the athlete's brains, perhaps the reason for not seeing an effect of athletic experience comes from the lack of seeing a hand position effect at all. Since the images in our study were likely too complex to see PHE's, there were no PHE's for the athletes to show enhancement. The one time that we did see an enhancement as a result of athletic experience, it was accompanied by the graspability effect which was the most consistent across our dependent variables.

Future research should consider a paradigm that may be better suited to elicit PHE's, and then compare athletes to non-athletes. For example, a target detection task rather than a target discrimination task. According to Thomas and Sunny (2019) this should prime visual processing back towards the dorsal stream of vision, enabling PHE's. Thomas and Sunny (2019) also suggested incorporating some kind of motion in the target detection task. The dorsal stream of vision is said to be the, "action" pathway (Goodale & Milner, 1992), so incorporating some kind of motion in a target detection task could serve to further bias visual processing towards the dorsal stream. Detecting objects that are in motion would also be further in an athlete's favour, as no sport is performed without any kind of motion or motion recognition.

Finally, if PHEs only occur under precise conditions involving simple visual stimuli, it raises the question of whether or not PHEs are relevant to the daily experience of the average person, and the answer is perhaps not. According to the literature, it could be that the typical adult visual cortex is very capable of processing information effectively – regardless of athletic experience. However, PHE's could still be highly relevant for young children whose visual cortex is still developing, or adults who have suffered trauma to their visual cortices, or people who were born with congenital defects that affect the development of their visual cortex. In all of these cases, it could be that PHEs might contribute significantly to visual processing in the dorsal stream in order to compensate for reduced functioning of the visual cortex. The results of the present study lend support to the idea that the visual processing of graspable objects may be more efficient than non-graspable objects. If future research confirms this to be true, it could be important for rehabilitation of patients with blindsight. Perhaps rehabilitation protocols that use graspable images would be more effective at stimulating disconnected areas of the brain, or inducing surrounding areas to take on the role of damaged ones. Furthermore, perhaps children who are born with visual defects could have their symptoms ameliorated by early training with graspable objects.

Conclusion

Although we found some interesting significant results that warrant further investigation, our results did not support our hypothesis that athletic experience would lead to enhanced visual processing within peri-hand space. In fact, we did not find any PHE's at all. While the idea that athletic experience has widespread effects on the physiology of the brain is well supported (Pi et al., 2019; Gao et al., 2019; Zwierko et al., 2010; Biggio et al., 2017), as is the idea that visual processing is altered in near-hand space (Abrams et al., 2008; Adam et al., 2012; Chan et al., 2013; di Pellegrino & Frassinetti, 2000; Gozli et al., 2012; Reed et al., 2006; Schendel & Robertson, 2004) it is possible that athletes do not rely on peri-hand space at all to compete in their sports. Some literature suggests that the visual pathway implicated in peri-hand space recedes with age (Mundinano et al., 2019). Perhaps athletes are able to perform their skills due to enhanced processing in the visual cortex. There is also the possibility that our paradigm was not suited for seeing PHE's. The present graspability results suggest that perhaps patients with blindsight, or other sensorimotor impairments could potentially be helped by training with images of graspable objects rather than images of non-graspable objects, in order to further bias their visual processing towards their dorsal stream of vision.

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